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Shifting Covert Attention to Spatially Indexed Locations Increases Retrieval Performance of Verbal Information

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Abstract

People look at emptied spatial locations where information has been presented during encoding. There is evidence that this so-called *'looking at nothing'* behaviour plays a functional role in memory retrieval of visuospatial and verbal information. However, it is unclear whether this effect is caused by the oculomotor movement of the eyes per se or if covertly shifting attention is sufficient to cause the observed differences in retrieval performance. In an experimental study ($N = 26$), participants were manipulated in being able to shift either their eyes or their focus of attention to a blank spatial location whilst retrieving verbal information that was associated with the location during a preceding encoding phase. Results indicate that it is not the oculomotor movement of the eyes that causes the facilitation while retrieving verbal materials, but rather covert shifts of attention are sufficient to promote differences in retrieval performance.

Keywords: memory retrieval; eye movements; visuospatial attention; memory representation; encoding-retrieval relationship

Introduction

We encode the stimulus location regardless of the task (e.g., Andrade & Meudell, 1993). When we attempt to retrieve the information, we automatically recall the location of the stimulus, even if the stimulus is no longer present. Recent research has shown that people even look at emptied spatial locations where information was presented during encoding when retrieving information that is associated with this location (e.g., Altmann, 2004; Jahn & Braatz, 2014; Richardson & Kirkham, 2004; Richardson & Spivey, 2000; Scholz, Helversen, & Rieskamp, 2015). There is evidence that this so-called *'looking at nothing'* behaviour plays a functional role in memory retrieval of visuospatial (e.g., Johansson & Johansson, 2014) and verbal information (Scholz, Mehlhorn, & Krems, 2014). In the study by Scholz et al. (2014), participants had to retrieve pieces of auditorily presented information that were associated with a spatial location on a computer screen during a preceding encoding phase. Retrieval performance was higher when participants fixated on the area associated with the to-be-retrieved information than when fixating on another area. This result shows a *facilitatory effect* of memory retrieval that can be explained by an overlap between processes engaged in the encoding and retrieval of verbal information from memory. It remains unclear however which exact mechanisms drive this facilitatory effect. Two likely candidates are the oculomoter movement of the eyes or covert shifts of attention (e.g., Richardson & Spivey, 2000; Thomas & Lleras, 2009).

Guérard and Tremblay (2011) suggest that presented information is automatically encoded in an internal memory representation, (a common map) *independently* of whether it needs to be remembered or can be ignored. We thus encode the location of information even if it is irrelevant to the task. 'Spatial indexes'are assumed to function the role of linking elements in the internal memory representation with the external world (e.g., Pylyshyn, 2002; Laeng, Bloem, D'Ascenzo, & Tommasi, 2014). The spatial index is stored as part of the internal representation and drives the eyes back to associated spatial locations (Richardson & Kirkham, 2004). Consequently, in order to explain the facilitatory effect of the looking at nothing behaviour, addressing the spatial index by shifting attention to associated but emptied spatial locations could be sufficient to elicit enhanced retrieval performance. Several findings support this assumption. Godijn and Theeuwes (2004) demonstrated that attention is focused at the saccade target location just prior to the saccade being executed. Furthermore, attention influences what is remembered between eye movements; it selects objects for visual processing, guides motor action, and facilitates storage in working memory (e.g., Deubel & Schneider, 1996; Theeuwes, Kramer, & Irwin, 2010).

Although attention usually precedes eye movements (Deubel & Schneider, 1996), attention and eye movements are still distinguishable processes that can be separated (Theeuwes, Belopolsky, & Olivers, 2009; Thomas & Lleras, 2009). Thomas and Lleras (2009) for instance showed that insight problem solving can be enhanced by covert shifts of attention independent of eye movements. They asked participants to solve Duncker's radiation problem and instructed them to simultaneously track random digits which appeared in an order representing the solution of the problem. The two groups either tracked the digits with their eyes or with their attention whilst keeping their eyes at the centre of the screen. Both groups solved the problem faster than a group which observed digits appearing only at the centre of the screen. This experiment illustrates two things; firstly when participants separated eye movements and shifts of attention, they performed equally, and secondly, attention shifts appear to be sufficient to guide insight. Another study carried out by Richardson and Spivey (2000) showed that looking at nothing behaviour exists even when participants do not execute eye movements during the encoding phase. During encoding in an initial step, participants observed a grey matrix with four quadrants. A mask window then closed into the centre of the screen. The matrix moved behind the mask window to bring each quadrant to the centre of the window, and subsequently an auditory sentence was presented. After the presentation of four sentences, the window expanded outwards. During retrieval, participants saw the empty matrix and were probed to retrieve one of the sentences. The experiment demonstrated that people looked at a blank region on a screen during retrieval, even when it was unnecessary to move their eyes during encoding. These results may suggest that it is not the oculomotor movement of the eyes but covert shifts of attention that lead to enhanced memory retrieval when looking at nothing.

In order to test this assumption, an eye tracking experiment was conducted. Similarly to Richardson and Spivey (2000), participants listened to four sentences in each trial. Each sentence was associated with a spatial area henceforth called 'relevant quadrant'of a grey two by two matrix on the computer screen. In a retrieval phase, participants judged a statement regarding one of the before heard sentences to be true or false. Simultaneous to this task, participants were asked to solve a tracking task (see Thomas & Lleras, 2009), undertaken to manipulate participants' eye movement behaviour/shifts of attention. Given previous findings (Johansson & Johansson, 2014; Scholz et al., 2014), firstly, it was assumed that participants would reach higher response accuracy scores when being guided to the quadrant where the to-be-retrieved information was presented during encoding (match condition). When participants' eye movements or their attention was guided away from the location associated with the to-be-retrieved information, the study expected to find no facilitation effect resulting in lower response accuracy (mismatch condition). When participants looked at the centre of the screen (central condition), response accuracy was expected to fall in between the match and mismatch conditions. This is due to the participants' gaze or attention being located at a relatively short distance away from the relevant quadrant (i.e., shorter than 15°of visual angle as suggested by results on the so-called 'useful field of view', for an overview see Irwin, 2004). Secondly, this study assumes that eye movements do not have advantages over attention shifts for rehearsing verbal information in working memory. It is expected therefore that response accuracy should not differ between the attention shift and eye movement conditions.

Method

Participants

Twenty-six students (21 female, 24 years, ranging from 20-32 years) enrolled at the Technische Universität Chemnitz volunteered in the experiment in exchange for student course credit or monetary compensation. All participants had normal or corrected to normal vision and were native German speakers.

Apparatus and Stimuli

The study recorded gaze data using a binocular IViewX RED eye-tracking-system from SensoMotric Instruments with a sampling rate of 120 Hz. Data was analyzed with BeGaze 3.0, Microsoft Excel 2007 and IBM Statistics 19 (SPSS).

Stimuli was presented on a 22 inch computer screen using EPrime 2.0 software and with a resolution of 1680×1050 pixels. All subjects were seated at a distance of 600 mm in front of the screen. Visual stimuli consisted of grey two by two matrixes with quadrants sized at a height of 14.25° of visual angle and a width of 15.97° visual angle (Figure 1). During encoding, participants observed a white circle with a speaker symbol located in the centre of the spatial areas or quadrants. During retrieval, participants viewed a circle with random digits appearing in one of five locations, alternating with an empty matrix in a randomized order and with a frequency 1 Hz (tracking task, see Thomas & Lleras, 2009). Within each trial the digit always appeared in the same circle. Circles with speaker symbols or digits were of equal size with a visual angle of 2.4°. Digits had a size of approximately 1.2° visual angle. The distance between the centre of the screen and the circles in the quadrants was 9.5° visual angle.

The auditory material was presented using Sinnheiser HD270 headphones. Four facts were presented during each encoding phase. One of these facts was tested during the subsequent retrieval phase. Material for the encoding phases consisted of 32 sentences involving fictitious scenes with a name of an artificial city and four attributes (e.g., 'In Rinteln you can find a main station, a video store, a silver mine and a television tower.'). Auditory materials for the retrieval phases consisted of eight statements. Each statement was a true or a false version referred to in one of the attributes of one of the sentences presented during the encoding phase (e.g., 'In Rinteln you can find a main station.' true, attribute 1).

Design and Procedure

After the instructions and a calibration phase, the experiment began with two practice trials which adhered to the same procedure carried out in the test trials. Subsequently eight experimental trials were undertaken. Each trial followed the same procedure and was divided into an encoding and a retrieval phase (see Figure 2). During the encoding phase, participants heard four sentences, with each sentence being associated with one quadrant on the screen. Participants were instructed to listen carefully and memorize the sentences to

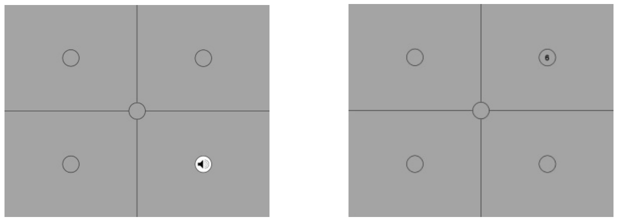

Figure 1: Example of visual stimulus material during encoding (left side) and retrieval (right side)

the best of their ability. After the presentation of a fixation cross, the retrieval phase was initiated. Participants heard one test statement and were instructed to judge whether this statement was true or false by selecting a blue (true) or red (false) button on the keyboard. While providing the answer, participants were instructed to react to the digits of the tracking task by pressing the space bar on the keyboard. The digits of the tracking task either appeared in the relevant quadrant (match condition, two trials), in one of the adjacent quadrants (adjacent condition, two trials), in the diagonal quadrant (diagonal condition, two trials) or in the centre of the screen (central condition, two trials). Trials with the digits in the adjacent and diagonal quadrants were combined to a mismatch condition because this study did not expect differences to exist between these trials. The tracking task was designed to enable or disable looking at nothing behaviour by guiding participants' eyes either to the relevant quadrant or away from it (eye movement condition).[1] In a second experimental group, participants were asked to fixate on the centre of the screen and to react to the digits by covertly shifting their attention towards them (attention shift condition). The study consisted of a 3×2 design. Whereby the variable tracking task was varied within participants (match, mismatch, central) and the variable gaze instruction (attention shift vs. eye movement) was manipulated between participants.

Analysis

To analyze whether covert shifts of attention or eye movements lead to differences in retrieval performance, gaze patterns and performance in the tracking task were initially tested to ensure that the manipulation had been successful.

In order to analyze gaze patterns, five Areas of Interest (AOIs) were defined by positioning circles around the speaker symbols or digits on the quadrants as opposed to the centre of the screen. Fixations were defined by a dispersion threshold of 100 pixel and a duration threshold of 100 ms. Mean fixation times were aggregated over the trials and for the participants in each AOI.

To analyze the performance of the tracking task, two measures were compared (see Thomas & Lleras, 2009). Firstly, the average reaction time between the onset of a digit featuring on the screen to the reaction of a participant in pressing the space bar was recorded. Reaction times were expected to be similar over all the conditions, because tasks were equal for both groups excluding the gaze instruction. The second measure used in the comparison was the digit identification accuracy (DIA) between the count of digits a participant reacted to and the count of digits a participant observed until they selected the response button. Again, no differences were expected between the two experimental groups. The dependent measure was the retrieval performance, which was assessed as the mean percentage of correct answers for each condition. All trials were aggregated for each condition (match, mismatch, central) for all participants.

Results

Manipulation check

It was necessary to exclude four participants (one participant in the eye movement condition and three participants in the attention shift condition) because more than 50 % of their fixation time fell at the centre of the screen and less than 25 % was located in the quadrant with the speaker symbol during all the trials of the encoding phase. As shown in the upper part of Table 1, the remaining participants fixated for the majority of the time the quadrant in which the speaker symbol was presented (attention shift condition: $F(4,40) = 17.43, p < .001; \eta_p^2 = .64$; Bonferroni pairwise comparisons all $ps < .001$; eye movement condition: $F(4,60) = 29.07, p < .001; \eta_p^2 = .66$; Bonferroni pairwise comparisons all $ps < .001$). During the retrieval phase (middle part of Table 1), participants in the attention shift condition followed the instruction and fixated at the centre of the screen for a longer duration than on any quadrant ($F(4,37) = 12.38, p < .001; \eta_p^2 = .57$; all $ps < .001$). In the eye movement condition, participants followed the digits with their eyes and fixated on the field showing the digit significantly longer than on any other quadrant ($F(4,59) = 6.93, p < .001; \eta_p^2 = .32$; Bonferroni pairwise comparisons all $ps < .01$). The difference however in fixation duration between the quadrant featuring the digit and the centre of the screen is not significant ($p = 1.0$). Nevertheless with a mean fixation duration of 3326 ms, participants looked on average approximately 47.26 % of the time at the quadrant featuring the digit, which is well above the chance level of 20%. A one sample t-test supports this statistic ($t(12) = 6.84, p < .001, g = 1.98$). Participants of both groups performed comparably well in the tracking task (lower part of Table 1). Calculating a two sample t-test this study did not find any significant differences in the reaction times to the digits ($t(20) = 1.04, p = .31$) or the digit identification accuracy ($t(20) = -0.70, p = .50$) between the attention shift condition and the eye movement condition.

[1] Eye movements have also been called 'overt shifts of attention'(Theeuwes et al., 2009). In this study, we label the condition 'eye movement'to emphasize that this condition includes an oculomotoric movement of the eyes.

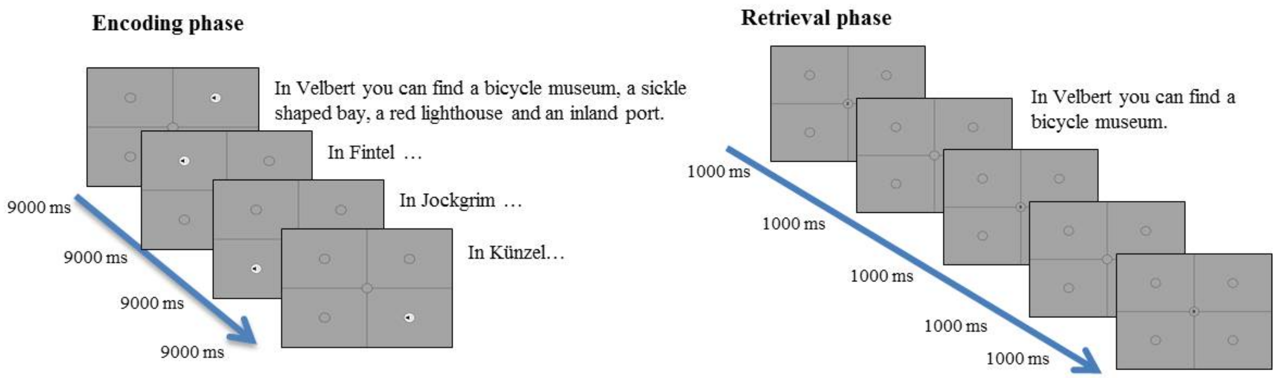

Figure 2: Example trial for the encoding phase (left side) and the retrieval phase with the tracking task (right side). Original materials in German.

Response accuracy

This study assumed superior retrieval performance in the match compared to the mismatch condition and that the retrieval performance in the central condition could fall in between the performance of the match and mismatch conditions. Furthermore, concerning the gaze instruction, no differences were assumed between the attention shift and the eye movement conditions. Figure 3 shows the results of the gaze instruction and tracking task manipulations on response accuracy. To test our hypotheses, we calculated a *contrast analysis for comparing hypotheses* (see Rosenthal, Rosnow, & Rubin, 2000). We chose this analysis, because it allows testing more precise hypothesis and with a higher statistical power than a standard analysis of variance (ANOVA).[2] Generally, in contrast analyses, the fit between a model (conveyed by contrast weights) and the data for a given participant is expressed in a single value, most commonly an L-value (Rosenthal et al., 2000, p. 128-130). In our case, L-values for two different models are calculated as the product of the weights of the models and the corresponding response accuracies (Model A: Eye movements do not have an advantage over shifts of attention. Participants in both conditions show the highest response accuracy in the match trials and lowest response accuracy in the mismatch trials.; Model B: Eye movements drive the facilitation effect in the looking at nothing paradigm and only participants in the eye movement group show higher response accuracies in the match trials.). Higher L-values indicate better fits between a model as specified by its contrast weights and the data. An univariate F-test tests which of the two models better fits with the data. If Model A better fits with the data than model B, the difference of the L-values (Model A $-$ Model B) should lead to a positive F-value. The p and η_p^2 values indicate the significance and effect size of the observed difference. To reflect our Model A, we assigned the match trials in both gaze instruction conditions with a contrast weight of $+1$, the central trials with 0 and the mismatch trials with -1. To reflect our Model B, we assigned contrasts similar to Model A but only for the eye movement condition and 0 for all trials in the attention shift condition. The results reveal a positive F-value which is highly significant ($F(5,60) = 50.28, p < .001; \eta_p^2 = 0.81$) giving strong support to our Model A that assumed differences in the conditions of the tracking task, but no differences in the variable gaze instruction. To further show that no meaningful differences between the gaze instruction conditions exist we calculated a two samples t-test comparing response accuracy for the match condition between the eye movement and the attention shift conditions. The test indicates no significant difference between gaze instructions in the match condition ($t(20) = 1.42, p = .17, d = 0.65$). Therefore our results suggest that the mere shift of attention facilitates memory retrieval in the looking at nothing paradigm and that eye movements to nothing have no advantages over attention shifts (Figure 3).

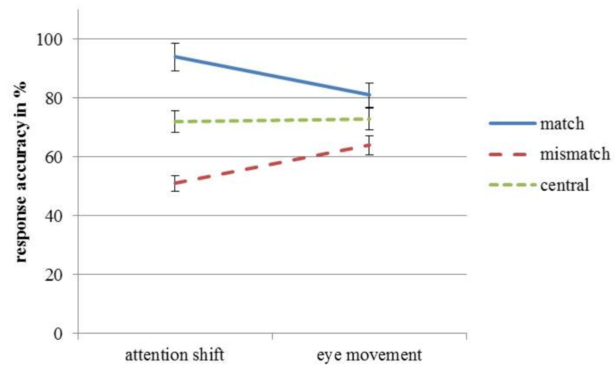

Figure 3: Mean response accuracy for the three conditions of the tracking task (match, mismatch, central), between the two conditions of the gaze instruction (attention shift, eye movement). Error bars represent standard errors.

[2]Furthermore, when the sample size is small like in this study, non-significant results of a ANOVA can be hard to interpret.

Table 1: Means (*SDs*) of fixation times and of performance in the tracking task.

		Gaze instruction	
		Eye movement condition	Attention shift condition
Encoding	Mean fixation times to speaker symbol	2015 ms (685)	4555 ms (2031)
	Mean fixation times to other quadrants	526 ms (400)	465 ms (499)
	Mean fixation times to centre	408 ms (232)	2864 ms (1619)
Retrieval	Mean fixation times to digit	3326 ms (1752)	3028 ms (1445)
	Mean fixation times other quadrants	1233 ms (1295)	1939 ms (2106)
	Mean fixation times to centre	2416 ms (1601)	4861 ms (2555)
Tracking Task	Reaction times	661 ms (224)	585 ms (129)
	Digit identification accuracy	.74 (.22)	.80 (.16)

Discussion

The aim of the present study was to test whether the oculomotor movement of the eyes or covert shifts of attention are necessary to facilitate memory retrieval in the looking at nothing paradigm. To this purpose, this study manipulated whether participants looked at or shifted their attention covertly to the spatial area where the to-be-retrieved information was presented during encoding. A tracking task was carried out in which a digit either appeared in the spatial area associated with the probed information, or alternatively in the central area of a screen or in one of the adjacent or diagonal areas. Additionally, half the participants were instructed to look at a tracking task whereas the other half was instructed to merely shift their attention. Results show that the manipulation was successful. During encoding, participants looked the longest at the speaker symbol associating the auditorily presented information with the quadrant of the screen. Based on previous research on the looking at nothing paradigm, it can therefore be concluded that participants spatially indexed the location where the fact was presented (Richardson & Spivey, 2000; Richardson & Kirkham, 2004). During retrieval, participants were also successful in following the instructions. Most of the time, they looked at the digits in the eye movement condition. In the attention shift condition participants fixated the centre of the screen. Results do not show any significant differences in reactions to the digits presented in the tracking task. People needed equally long to react to the digits on the screen and reacted to about the same amount of digits. The fact that about 20 % to 25 % of the digits were missed in both gaze instruction conditions shows that the tracking task and the retrieval task challenged our participants and were not easy. The somewhat better results for the tracking task in the attention shift condition might be an indicator that participants in this condition stuck more precisely to our instructions. Taken together, participants in both conditions of the gaze instruction performed equally well. Although the key results are reported here the manipulation check leaves much room for further research and more precise examinations.

We expected participants to show higher retrieval accuracy when being guided towards a relevant quadrant during retrieval of verbal information than when being guided away from such a location. This manipulation was intended to replicate previous findings of a facilitation effect when looking at nothing behavior is executed with verbal material (Scholz et al., 2014). Furthermore, we did not expect differences in retrieval accuracy between participants that were covertly attending and participants that were moving their eyes to associated spatial locations. This was based on the assumption that attention shift is sufficient to aid memory retrieval and that eye movements to the relevant spatial area do not have benefits over covert shifts of attention. Our results confirm both hypotheses. Participants in the eye movement condition, as well as participants in the attention shift condition demonstrated increased retrieval accuracy when looking at/shifting attention to the relevant quadrant in comparison to any irrelevant quadrant. This study therefore concludes that it is not the oculomotor movement of the eyes per se that facilitates memory retrieval whilst looking at remembered locations, but rather it is the covert shift of attention that facilitates retrieval. Facilitation does not appear to be a consequence of mere oculomotor activity. It is important to recognize however that the wording 'facilitation effect' has to be used with care since we cannot present direct evidence that participants show improved retrieval performance when looking at or shifting attention to indexed location in comparison to freely looking at nothing. Nevertheless, if the results of the central condition in this study are interpreted as a control condition (due to no information being associated with the centre, and the centre always remaining at the same spatial distance to the speaker symbols), the data of the current study suggests a faciliatory effect when participants looked at the relevant quadrant, as well as an impaired effect when participants' eye movements or focus of attention was guided away. The current study reports evidence supporting the close relationship between eye movements, memory and attention (e.g., Belopolsky & Theeuwes, 2011). People build a mental representation consisting of information they are processing. This representation contains features like shapes and forms of objects, *and* it contains information concerning spatial locations. What exactly enters the mental representation is fundamentally influenced by attention (Theeuwes et al., 2009), and objects that are attended to are easier to process (Posner, 1980). Accordingly, the retrieval of information from memory is affected by shifts of attention to information held in memory. Simultaneously, a motor response is executed, leading the eyes to associated spatial locations. This process facilitates memory retrieval even if we do not execute the programmed eye movements. A reason for this might be that attention already shifts to the locations that have been associated with the to-be-retrieved information during the preceding encoding phase. Attention is the mechanism which integrates different forms of information (visual, auditory) together to form a multimodal memory representation (Theeuwes et al., 2010), and it is used to access this representation by orienting to the relevant information (Theeuwes et al., 2009).

In conclusion, to access parts of our mental representation, we direct our attention to certain features which activate the programming of corresponding eye movements. Since the programming of eye movements is highly connected to covert shifts of attention, this study concludes that it is not 'looking' at nothing which facilitates memory retrieval but rather it is an 'attention shift' to nothing.

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